Deployable CubeSat Antennas for Deep Space and Earth Science Missions

Nacer Chahat, Emmanuel Decrossas, David Gonzalez, Tom Cwik
Jet Propulsion Laboratory (JPL), California Institute of Technology, Pasadena, CA 91109 USA, nacer.e.chahat@jpl.nasa.gov

***Abstract*— New antenna technologies have unlocked a new class of missions using CubeSats for Earth Science or Deep Space operations. This class of small satellites have historically been mostly used as teaching tools allowing students to design and test small satellites and develop space experiments. With the rise of new game-changing antenna technologies, overcoming their small size and need for high gain, they can now be used beyond Low Earth Orbit (LEO). Over the past 5 years, technologists at the Jet Propulsion Laboratory have designed, tested and successfully flown these innovative Smallsat antennas, enabling new telecommunication and science achievements.**

***Index Terms*— Antenna, CubeSat, Deep Space, Low Gain antenna, LGA, High gain antenna, HGA, metasurface, patch array, loop, deployable, circular polarization.**

I. Introduction

Until a year ago, CubeSats were constrained to be used in Low Earth Orbit (LEO) only. One of the limiting factor preventing CubeSat from venturing into deep space to explore our solar system is the size constraint of each subsystem and sufficiently large RF aperture for communication [1]. In LEO, CubeSats employ UHF deployable dipole or S-band patch antennas, as low gain is sufficient to communicate with the large ground stations. For comparison, a LEO is an orbit with an altitude above Earth's surface of 2,000 kilometers; whereas deep space is for distances from Earth greater than 2 million km. Since CubeSat RF telecommunication output power resources are limited (~5 watt RF), a higher gain antenna is needed to compensate for the factor of 1000 increase in range. Extensive work was carried out at the Jet Propulsion Laboratory to develop new low-, medium-, and high-gain antennas primarily for deep space CubeSat communication at X- or Ka-band.

Multiple high-gain antenna technologies for CubeSats were developed: (1) deployable reflectarrays [1]-[2], (2) parabolic mesh reflector [5]-[8], (3) metal-only metasurface [9], (4) membrane antennas [10], and (5) inflatable antennas [11].

The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

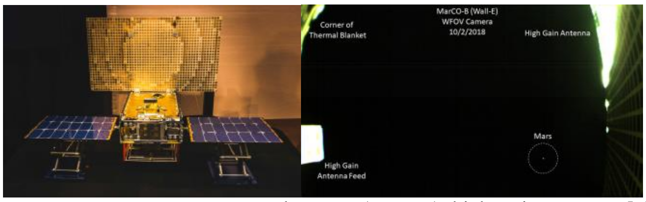
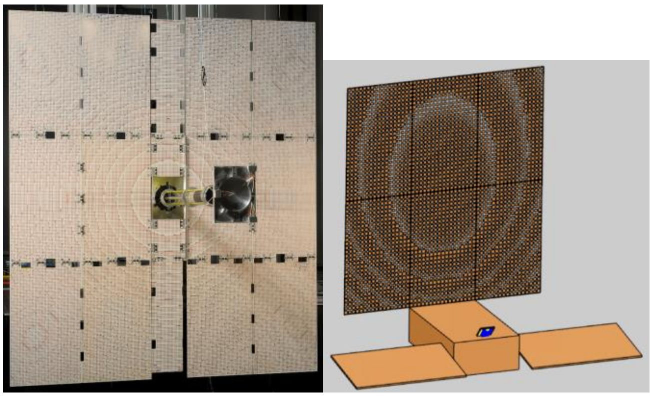


Fig. 1. NASA's JPL Mars Cube One (MarCO) high gain antenna [3] successfully deployed in space and on its way to Mars.



(a) (b)

Fig. 2. (Left) One-meter reflectarray antenna (OMERA) compatible with a 6U-class CubeSat [22]. (Right) X-band 60cm×67cm deployable reflectarray antenna for 6U-class CubeSat.

With the recent success of two major NASA's CubeSat mission, Mars Cube One (MarCO) [1] and Raincube [1], one can expect the use of CubeSat to increase rapidly in the near future.

II. CubeSat HGAs

The first deployable reflectarray was implemented on ISARA [2] (Integrated Solar Array and Reflectarray Antenna) which operates at Ka-band. This flight system was successfully tested on orbit. This work was extended to an X-band telecommunication system using a reflectarray deployed from a 6U cubesat jointly launched with the NASA InSIGHT Mars lander mission to provide bent-pipe communication relay during the entry, descent and landing (EDL) portion of that mission. The twin Mars Cube One [1],[2] (MarCO) spacecrafts successfully demonstrated the deployment of their reflectarray. A photography of the deployed antenna is shown in Fig. 1 while the cubesat is approaching Mars. A gain of 29.3dBic was demonstrated before launch and it was measured in space within 0.4dB of predicted performance while relying EDL data.

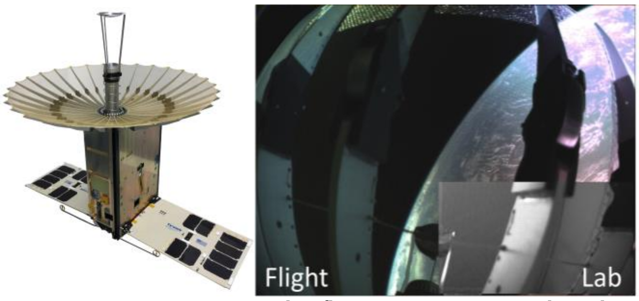


Fig. 3. NASA's JPL 0.5-m mesh reflector antenna on Raincube CubeSat [5] was successfully deployed and operated in-orbit.

The OMERA antenna [2] (One MEter Reflectarray Antenna) extends the size of the reflectarray to what is considered the largest practical for a 6U cubesat space system, stacking panels on four sides of the spacecraft bus and employing a unique telescoping feed from the center of the bus (Fig. 2a).

A larger deployable X-band reflectarray antenna is also under development at the Jet Propulsion Laboratory for a potential Mars Orbiter (Fig. 2b). This 60cm×67cm reflectarray antenna is compatible with 6U-class CubeSat and achieves a gain of 32dBic.

The RainCube mission is the first active radar in a CubeSat successfully deployed in Low Earth Orbit. It was enabled by a 0.5m mesh reflector from a 6U CubeSat to measure rain and snow precipitation [5]. More recently, anmoffset deployable mesh reflector was developed by Tendeg LLC [7]. Compatible with a 12U-class CubeSat, this antenna fits in a 3U volume and deploys into a large one meter parabolic reflector (Fig. 4). It was designed for telecommunication at X-band and Ka-band with the Deep Space Network [8]. This antenna was patented and licensed by a small company. The antenna demonstrates 56% efficiency with 42.6dBic of gain at Ka-band. It is commercially available for the rest of the world to use in future CubeSat missions.

The first metal-only metasurface (MTS) antenna was fabricated using metal additive manufacturing [9] (Fig. 5). It is operating at Ka-band in the downlink DSN frequency band (i.e. transmit only). The 10cm-diameter MTS antenna achieves 26.1dBic. Such an antenna can be printed on the bus surface using the largest side of the CubeSat as a radiating aperture.

III. Conclusion

This paper describes the CubeSat high-gain antennas developed at NASA for deep space and earth science missions. While deployable reflectarrays and mesh reflectors are now standards for CubeSat missions, we are maturing metasurface antennas for future missions. These deployable antennas have changed space exploration by enabling low-cost and quick turnaround missions.

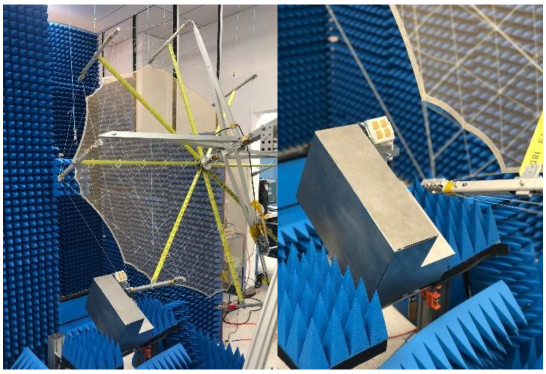


Fig. 4. One-meter deployable mesh reflector for deep space communication at X-, Ka-, or X/Ka-band [8]. The mesh reflector mechanical deployment is described in [7].

Fig. 5. Metal-only RHCP Ka-band metasurface antenna [9].

References

[1] N. Chahat, "A mighty antenna from a tiny CubeSat grows," IEEE Spectrum, vol. 55, no. 2, pp. 32-37, Jan. 2018.

[2] R. Hodges, D. Hoppe, M. Radway, and N. Chahat, "Novel deployable reflectarray antennas for CubeSat communications", *IEEE MTT-S International Microwave Symposium* (*IMS*), Phoenix, Az, May 2015.

[3] R. E. Hodges, N. Chahat, D. J. Hoppe, and J. Vacchione, "A Deployable High-Gain Antenna Bound for Mars: Developing a new folded-panel reflectarray for the first CubeSat mission to Mars," *IEEE Antenna Propag. Magazine*, vol. 4, April 2016.

[4] N. Chahat, M. Arya, J. Sauder, E. Thiel, T. Cwik, "Ka-band One-Meter Deployable Cassegrain Reflectarray Antenna for NASA's Radar Earth Science Mission," to be submitted to *IEEE Transaction on Antennas and Propagation*, 2018.

[5] N. Chahat, R. E. Hodges, J. Sauder, M. Thomson, E. Peral, and Y. Rahmat-Samii, "CubeSat deployable Ka-band mesh reflector antenna development for Earth Science missions," *IEEE Trans. Antennas and Propag.*, vol. 64, no. 6, pp. 2083-2093, June 2016.

[6] N. Chahat, R. E. Hodges, J. Sauder, M. Thomson, and Y. Rahmat-Samii, "The Deep-Space Network Telecommunication CubeSat Antenna: Using the deployable Ka-band mesh reflector antenna.," *IEEE Antennas and Propag. Magazine*, vol. 59, no. 2, pp. 31-38, April 2017.

[7] G. E. Freebury and N. J. Beidleman, "Deployable reflector," Patent WO 2017/131944 A4, Jan. 2016.

[8] N. Chahat, J. Sauder, M. Mitchell, N. Beidleman, and G. Freebury, "One-Meter Deployable Mesh Reflector for Deep Space Network Telecommunication at X- and Ka-band," submitted to *IEEE Transaction on Antennas and Propagation*, 2018.

[9] D. González-Ovejero, N. Chahat, R. Sauleau, G. Chattopadhyay, S. Maci and M. Ettorre, "Additive Manufactured Metal-Only Modulated Metasurface Antennas," *IEEE Transactions on Antennas and Propagation*, vol. 66, no. 11, pp. 6106-6114, Nov. 2018.

[10] M. Arya, J. Sauder. R. Hodges, "Large-area deployable reflectarray antenna for CubeSats," *SCITECH*, 7–11 January 2019, San Diego, CA.

[11] A. Babuscia, T. Choi, J. Sauder, A. Chandra and J. Thangavelautham, "Inflatable antenna for CubeSats: Development of the X-band prototype," *IEEE Aerospace Conference*, Big Sky, MT, 2016.